The persistent anomaly of summertime circulation over the Ural Mountains

LI Shuanglin[1], JI Liren[1] & NI Yunqi[2]

1. LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China;
2. Chinese Academy of Meteorological Science, Beijing 100081, China

Abstract **The tropical heating and transient activity features during the period of the persistent anomaly of summertime circulation over the Ural Mountains are studied, and a possible mechanism responsible for formation and maintenance of persistent anomalies is proposed. The mechanism can be summarized as a kind of self-sustaining through a two-way interaction of stationary wave with transient eddies under the consistent forcing of abnormal heating in the tropics.**

Keywords: persistent anomalies, tropical heating, transient forcing, planetary wave, two-way interaction.

The persistent anomalies of summertime circulation over the Ural Mountains are related closely to the draught/floods over East Asia. For example, the abnormal Meiyu in 1998 over the Yangtze River basin and the resulting floods, the severest one in the last about 50 years, are mainly ascribed to the persistent anomalies of the circulation over Eurasia, and one of the conspicuous features is long maintenance of the blocking over the Ural Mountains (persistent positive anomalies)[1]. Quite a few theories have been posed on the formation and maintenance of persistent anomaly at mid-and-high latitudes with intermediate time scale, among which the forcing from synoptic-scales eddy is one of importance, but the contribution from transients can be different with respect to different areas[2]. Transient forcing might play an important role in the Ural persistent anomaly[3]. However, the theory with emphasis on internal dynamics encounters with difficulties to explain the frequent occurrence and long duration of persistent anomalies in some years while not in other years. Some researches[1, 4] found that the summertime rainfall in China has some connection with the tropical SST, which suggests that the persistent anomalies over the Ural Mountains might also be related to abnormal tropical heating. In this note we will explore the possible connections, and study the formation and maintenance of the persistent positive anomalies with long duration and re-occurrence over the Ural Mountains from the viewpoint of joint functioning of tropical heating (external forcing) and transients (internal forcing). The summertime daily reanalysis of NCEP/NCAR from 1980 to 1996 and the analysis of NCEP in 1998 are employed for this study.

1 Persistent anomalies over the Ural Mountains and abnormal tropical heating

The ratio of 500 hPa height anomaly to zonal mean of climatological root-mean-square (RMS) along the same latitude is taken as a measure of anomaly. When it is greater than 0.9 (less than −0.9), and this remains more than 10 days, a positive (negative) persistent anomaly case is defined. Here height anomaly is difference of height from climatological trend value. The anomalies have been time-filtered by a 5-day running mean in order to get rid of the interruption of the defined events from synoptic-scale transient eddy. There are three major regions of maximum occurrence over the North Pacific, North Atlantic and the Ural Mountains area, respectively, at mid-and-high latitudes. But this definition is simple and suitable for tropics as well as extratropics.

The point (60°E, 60°N) is chosen to represent the Ural area. The criteria of height anomaly at 500 hPa corresponds to about 82 gpm. The calculated results in summers from 1980 to 1996 suggest total 13/9 cases of positive/negative anomaly over the Ural Mountains, respectively. The composite anomalies of height and stream function at 500 hPa are calculated, and *t*-test for significance of their difference to 0 is conducted. The results show that (ⅰ) the development of persistent anomaly is equivalent barotropic, which suggests that barotropic process plays an important role; (ⅱ) the circulation pattern is significantly different between positive and negative case over some regions of the tropical western Pacific and the Indian Ocean, and over the tropical eastern Pacific and Atlantic, aside from the Ural itself and some other regions at mid-and-high latitudes. This suggests that anomalies over the Ural Mountains do not occur alone, but are connected with tropical circulation, in turn, tropical heating anomaly.

Fig. 1(a), (b) displays the composite OLR anomalies of the positive cases and their difference to the negative cases, respectively. It can be seen that (ⅰ) there are positive OLR anomalies, thus weak convection activity over an east-west oriented areas from the equatorial mid-western Pacific to the Indian Ocean including the Bengal Bay, Indo-china Peninsula, South China Sea and the Philippines. There are negative anomalies, thus intensified convection over the areas from the tropical Indian Ocean and the south to Indonesia, which is located just south to the areas above. That the two areas have opposite OLR anomalies indicates that the ITCZ over the tropical western Pacific and Indian Ocean is located south to the normal. (ⅱ) There are negative anomalies, thus intensified convection activity over the subtropical central East Pacific and Atlantic (20°N or so) including the Gulf of Mexico and the Latin America. The main intensified area

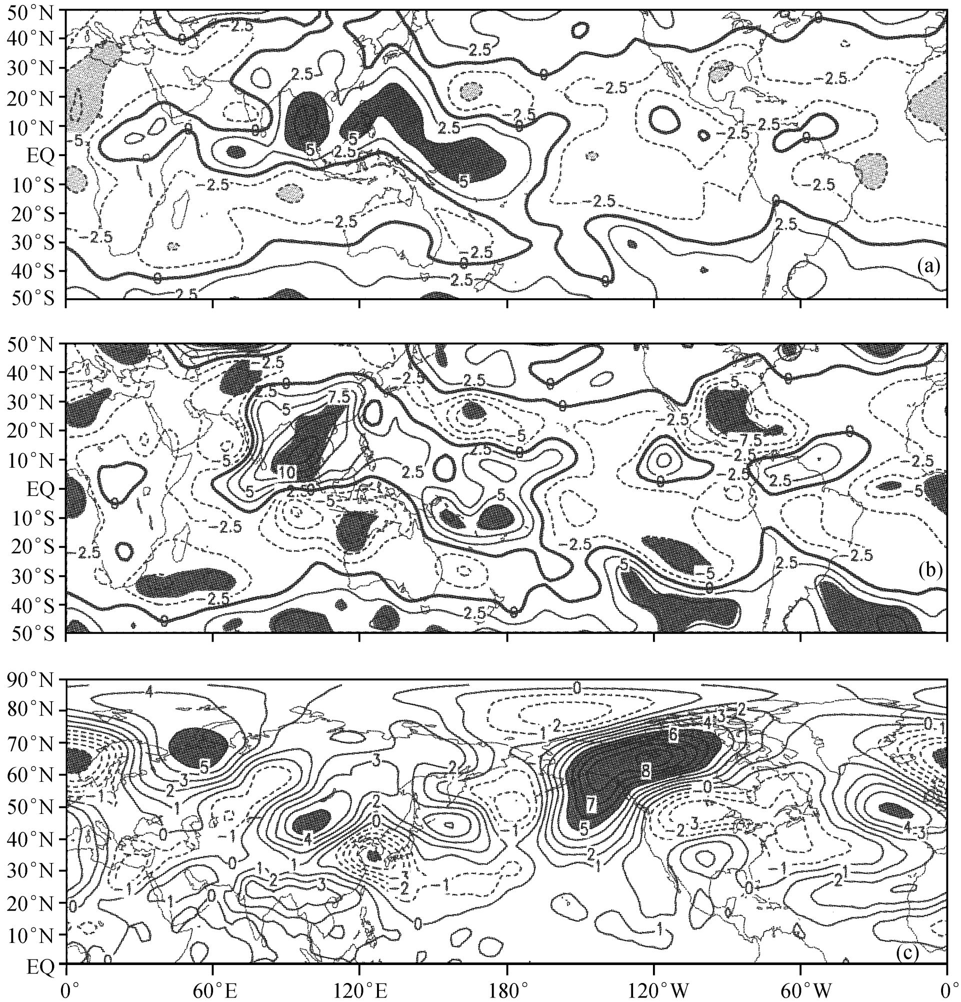

Fig. 1. (a) OLR anomaly during the positive cases over the Ural Mountains (unit: W/m^2). (b) OLR anomaly difference between the positive composites and the negative (unit: W/m^2). (c) Difference of 500 hPa height between the experiment EXP and CLI (unit: dam).

of convection is over the east-west oriented regions from the Gulf of Mexico to Hawaii. There are weak positive anomalies over the equatorial East Pacific and Atlantic. This shows that the ITCZ of the mid-eastern Pacific and Atlantic is located north to the normal, thus inducing stronger heating than the normal. One can see easily in fig. 1(b) that it is approximately opposite for the negative case. The shaded areas by *t*-test suggest that the main abnormal areas are significant. All these indicate that the tropical heating is abnormal significantly during the persistent anomaly period. We calculated composite anomaly of apparent heating source and moisture sink via circulation data according to thermodynamic equation, and got similar results. In their recent study on persistent anomaly of Summer Monsoon over the South China Sea, Ma et al.[1)] found that negative heating anomalies over the South China Sea, the Philippine and Indo-china Peninsula corresponds to positive height anomalies over the Ural during the negative anomaly period of summer monsoon. This confirms the results here from another aspect.

In order to demonstrate further the impact of abnormal tropical heating upon the Ural anomalies, we simulate the response of 500 hPa height to the tropical abnormal heating via ensemble integration of a general circulation model, IAP T42L9. A positive anomaly case with similar tropical heating anomaly in 1998 is adopted, which lasted 19 d from 17 July to 4 August. Two sets of experiment are conducted, namely control run (referred to as CLI) and anomalous heating run (referred to as EXP). In CLI, the deduced climate mean heating over tropics (30°S—30°N) is used to replace model diabatic physical processes, and remains unchanged during the integration. The climate

1) Ma Shujie, The research on the persistent anomaly of summer monsoon in the South China sea, Ph.D. Thesis, Institute of Atmospheric Physics, the Chinese Academy of Sciences, 2000.

mean heating is referred to the same period as the case. EXP is similar to CLI, except that the model heating is replaced by deduced mean heating of the case period. To get rid of stochastic influences of initial error, the ensemble with 5 members, which corresponds to 12UTC 14,15,16 and 00UTC 15,16 July 1998 individually, is used. By the evolution of the global RMS vorticity, total kinetic and potential energy, the spin-up time may be taken as about 4 or 5 days. Therefore, the contribution from tropical abnormal heating can be estimated by their comparisons of mean forecast height between the 2 sets of experiment from July 20 to 30.

Fig. 1(c) presents 500 hPa height difference of the 2 sets of experiment, from which one can see a positive anomaly center with maximum magnitude more than +50 m at the Ural Mountains, a negative center at the Baikal Lake downstream, and another positive center more than +20 m over the eastern Siberia and Okhotsk Sea. The 3 centers together make up an anomaly pattern similar to the typical “twin blockings” over Eurasia. Besides, there is anomaly less than –40 m over the coastal northern Atlantic to Europe, and a train positive-negative-positive anomaly centers from the America to the Atlantic. Comparing fig. 1(a) with the quasi-stationary wave during the case (not shown), one can see that they are in phase, but magnitude of the former (50 m) is much smaller than the latter (140 m). In a word, the simulated results demonstrate that the tropical abnormal heating favors the quasi-stationary response of positive height anomalies over the Ural Mountains.

2 Transient activity and persistent anomaly

500 hPa band-pass height variance with synoptic-scale (2.5—6 d) can represent transient activity. The calculated results suggest two major regions of transient activity over the North Pacific and the eastern North America to Atlantic, respectively, which are consistent with climatology. Fig. 2(a) shows the composite comparison of positive anomaly to the climatology, from which one can see positive anomalies of transient activity, thus intensification of transients over the central northern Atlantic to the coastal western Europe, Kara Sea, the region north to Baikal Lake, the central North Pacific and Northeast Canada. One can also see negative anomalies, thus weakness of transients over the central North America to the eastern coast of Atlantic, the Ural Mountains, Okhotsk Sea and the Arctic north to the Boring Sea. The maximum anomalies are situated in the area from the middle of North Atlantic to the coastal area of Europe, upstream of the Ural. For the negative anomaly cases, the calculated results are approximately opposite to the positive. The similar results can also be found from 200 hPa eddy Kinetic (not shown). In the following section, numerical simulations via a barotropic linear primitive model will be conducted to demonstrate the impact of anomalous transients, as far as the positive anomaly is concerned.

An initial perturbation, with maximum vorticity of $5.0\times10^{-6}\ s^{-1}$ at the point (0°E, 55°N) and distributed in an ellipse with long axis of 60° longitude and short axis of 20° latitude, is imposed. This corresponds to a short-wave trough imposed along the eastern coast of Atlantic, upstream the Ural Mountains. This also represents the synoptic observation that small troughs occur frequently upstream when the Ural positive anomaly is developing. The experimental results indicate that positive height anomalies will occur under the time-mean flow of positive anomaly from day 3 to day 7, but with maximum center northward somewhat. Fig. 2(b) presents the height response on day 7, from which one can see positive height anomalies over the Ural Mountains, which demonstrates that a positive vorticity perturbation upstream under time-mean flow of positive anomaly will result in positive height anomalies after day 3. The results under climatology time-mean flow are similar (not shown).

Normally the perturbation upstream is not certain to have positive vorticity, but often is alternate with time. Below an ideal perturbation source as Shutts[5] is imposed over the same region as above. The initial perturbation source evolves periodically and has the initial vorticity formula as follows:

$$F = F_*(x, y)\cos(2\pi\ t/\tau),$$

where $F_* = F_0\cos(\pi(\theta_x - \theta_1)/\Delta\theta)\cos(\pi(\varphi_y - \varphi_1)/\Delta\varphi$. τ is equal to 5 days, $F_0 = 5.0\times10^{-6}\ s^{-1}$. Comparing height response over the Ural under two time-mean flows, we can also see positive height anomalies. These results show further that the enhancement of transients upstream is in favor of positive anomalies over the Ural Mountains.

The results by two different time-mean flows, one corresponding to the period of positive anomaly and the other to climatology, are similar, which may be related to the fact that both of them have similar stationary wave. The calculation of 500 hPa height deviation from zonal mean $(\overline{H}^* = \overline{H} - [\overline{H}])$ shows that quasi-stationary wave during positive anomaly is indeed in phase of climatology, but with greater amplitude. This also indicates that the climatological background circulation governed by topography and land-sea thermal contrast is in favor of positive height anomalies over the Ural, and thus results in the regional preference of persistent anomaly.

The other aspect of the problem is: once the positive anomalies occur over the Ural, whether the associated planetary wave will favor the organization of transient eddies upstream, which, in turn, is conductive to the development and maintenance against dissipation. This problem will be addressed by means of a linear model referred to as a storm-track model (here the major region of transient activity is referred to as storm track).

The idea is like this: given a time-mean basic flow and initial perturbations distributed in the globe and inde-

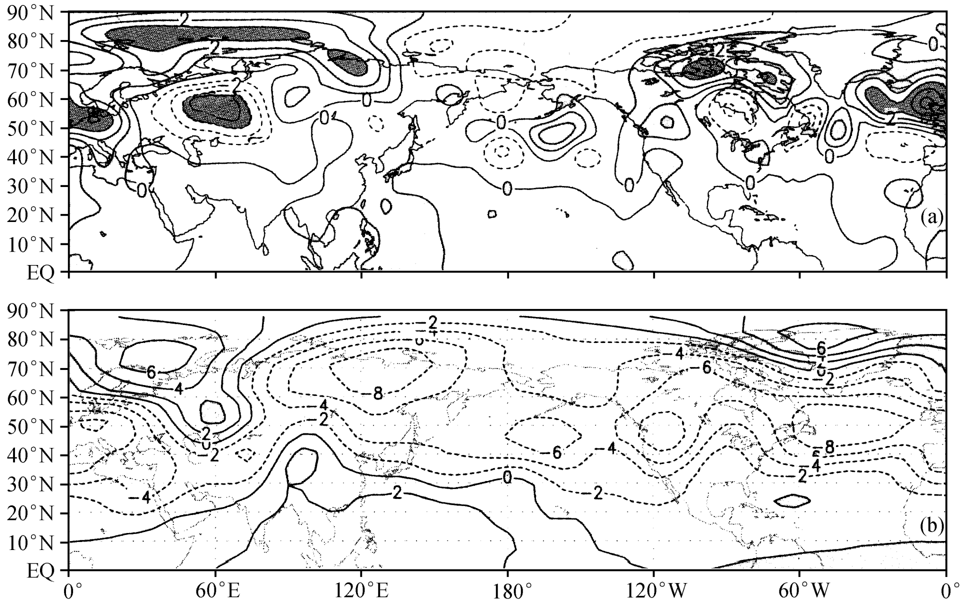

Fig 2. (a) The comparison of transient height variance of positive cases at Ural to climatology for the same term (unit: 10^2 dam^2). (b) 500 hPa height on day 7 of ideal initial perturbation upstream the Ural Mountains under positive anomaly basic flow (unit: gpm). Interval: 2.

pendent of each other, the results to integrate a storm track model several days forward will show that the perturbations at various regions do not develop and evolve in the same manner because of zonal asymmetry of time-mean flow. And some develop rapidly while others do not. If many such experiments (at least 30 times) are performed, a climatology of transient activity (storm track) can be built up by computing the statistical quantity of transients. By tuning the relevant parameters, this climatology can be adjusted to approximate the observed bandbass transients. This means that the storm track can be approximated in a model without the nonlinearity process, so the model can be referred to as a stormtrack model. A storm track model contains the influence of time-mean flow upon transients, but not the feedback of transient upon time-mean flow. Therefore, the role of time-mean flow in organization and steering of transients can be estimated by comparison of storm tracks with different time-mean flows. Branstator[6] constructed a storm track model in baroclinic framework to study the organization of transients by low-frequent anomaly pattern.

Based on a barotropic primitive equation spectral model, a barotropic storm-track model has been designed. Two time-mean flows were adopted for calculation: (1) the composite of positive anomaly cases over the Ural Mountains, and (2) the modified flow on basis of (1), where the height anomalies and corresponding vorticity over the Ural Mountains is diminished to 1/5 of their original magnitude. Therefore, (2) is different from (1) only over the Ural Mountains. Fig. 3(a) displays the 500 hPa height corresponding to (2). Fig. 3(b) presents the simulated variance of transient height under the time-mean flow (1). The two major regions, respectively over the North Pacific and the North Atlantic, can be seen, which is consistent with the observation. Fig. 3(c) illustrates the difference of transient height variance of the two time-mean flows. One can see that the Ural Mountains and the adjacent area are dominated by negative value, while positive difference mainly appear over the area from the mid-Asia to the Baikal Lake, coastal Kara Sea, eastern part of the North Pacific, and in particular, the coastal western Europe upstream of Ural. This suggests the decrease of transient activity over the Ural Mountains but the increase at the coastal western Europe when the positive height anomalies over the Ural intensify.

The results above indicate that the development of the height ridge over the Ural Mountains will be in favor of the enhancement of transients upstream, and the stronger the ridge, the more favorable. In other words, the planetary wave with positive height anomalies over the Ural as a basic flow is conductive to the organization and strengthening of transients upstream.

3 Conclusions

As for the positive anomaly cases, we have demonstrated: (ⅰ) the specific tropical abnormal heating distribution is in favor of formation of positive height anomalies over the Ural; (ⅱ) transients tend to organize over the coastal Europe when positive height anomalies occur over the Ural; (ⅲ) the intensification of transients along the coastal Europe upstream of Ural will be favorable for the development of positive height anomalies over the Ural Mountains. Combining all these three aspects, a possible mechanism of the formation and maintenance of persistent positive anomaly over the Ural Mountains is proposed, which can be described as below: first, specific abnormal

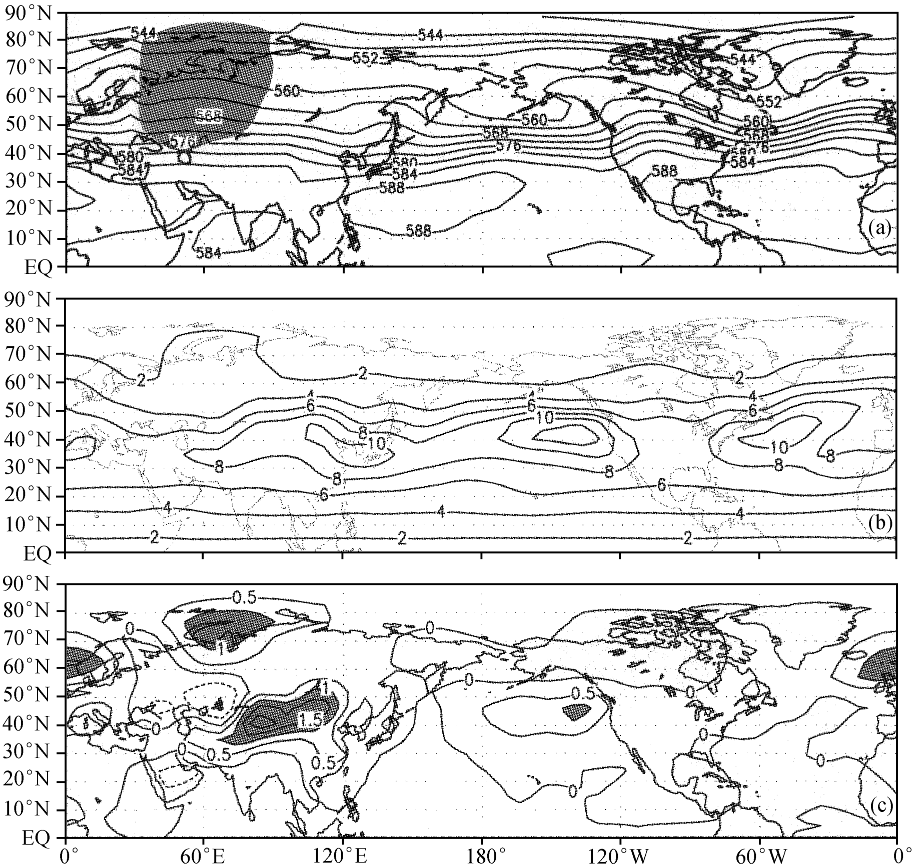

Fig. 3. (a) The modified time-mean flow (height at 500 hPa) based on the composite of positive cases, shaded is the modified region of height anomaly (unit: dam). (b) the variance of transient height of storm track model under positive anomaly flow (unit: dam^2) (c) the difference of transient height variance between positive anomaly flow and modified flow (unit: dam^2).

heatings occur over some tropical areas, especially over the central western Pacific, Indian Ocean and Atlantic. These abnormal heating will induce the response of positive height anomalies over the Ural, hence, a flow pattern of two ridges with a trough in-between over mid-latitude of Eurasia. Though the height anomalies over the Ural are not great enough to satisfy the anomaly criteria (blocking strength), the corresponding planetary wave will be in favor of the eastward shift of the storm track of Atlantic and the enhancement of transients at the coastal Europe upstream. The enhanced transient activity upstream, in turn, will lead to the strengthening of positive height anomalies over the Ural, which will result in the further organization of transient over the coastal Europe. The physical process can be summarized as a two-way interaction and positive feedback between transients and planetary flow under the consistent forcing of specific tropical heatings. In this way, the positive anomaly over the Ural can be established and maintained for a long time. As for the negative anomaly cases, we have shown the associated tropical heating anomalies and transient activity anomalies are opposite to the positive. Therefore the mechanism above on the basis of linear theory may also be applicable.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 49775261), the "Research Program for State Excellent Key Laboratory (Grant No. 49823002), and the Study on Formation Mechanism of Key Weather Disaster in China (Grant No. 97-13G-21).

References

1. Tao Shiyan, Zhang Qingyun, Zhang Shunli, The climate background and large-scale circulation features during 1998 floods disaster over Yangtze River Basin, Climatology and Environment Research (in Chinese), 1998, 3(4): 290.
2. Liu Hui, Wu Guoxiong, The maintenance of northern hemispheric blocking anticyclone, Part Ⅰ: the analysis of quasi-geostropic potential vorticity, Acta Meteorologica Sinica (in Chinese), 1996, 10: 142.
3. Dole, R. M., Gordon, N. D., Persistent anomalies of the extratropical Northern Hemisphere wintertime circulation: geographical distribution and regional persistent Characteristics, Mon. Wea. Rev., 1983, 111: 1567.
4. Wang, H., The interannual variability of the East Asian monsoon and its relationship with SST in a coupled atmosphere-ocean-land climate, Adv Atmos. Sci., 2000, 17: 31.
5. Shutts, G. J., The propagation of eddies in diffluent jet stream: eddy vorticity forcing of 'blocking' flow fields, Quart. J. R. Met. Soc., 1983, 109: 737.
6. Branstator, G., Organization of storm track anomalies by recurring low-frequency circulation anomalies, J. Atmos. Sci., 1995, 52(2): 207.

(Received January 11, 2001)